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ABSTRACT

A method to facilitate medical students' skill in diagnosis, based on cognitive science, was studied. A teaching intervention consisting of a 6-week seminar was used with sixth-year medical students in pediatric cardiology, which was their last rotation. Students were instructed to think about medicine as experts do (i.e., to conceptualize knowledge as consisting of parts that are related in a variety of ways, and which can be regarded as chunks). Objective was to determine whether the reorganization of knowledge structures acquired from preclinical lectures and from textbooks can be mediated by medical school instruction. Instruction used case histories and was based on the conceptual change model of learning. Criteria used to distinguish experts from novices were: correct diagnosis, kinds of knowledge structures/strategies used, whether the concepts are linked, and whether only relevant concepts are used. Eleven control group and 12 experimental group students were assessed using a pre- and post-test instruction design. Students were asked to diagnose by reporting aloud any thoughts they had in formulating a diagnosis. It is concluded that the teaching intervention introduced through this pilot study did improve students' thinking, but that the study needs further development. Appendices contain a verbatim transcript of the comments of a student and examiner and three case studies. A 47-item bibliography is included. (SW)

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TEACHING AND LEARNING IN MEDICINE: A COGNITIVE SCIENCE APPROACH

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This study makes use of current ideas in the domain of cognitive science, and explores a possible method of facilitating the qualitative change from novice to expert in students' ability to make medical diagnoses. The theoretical background to this study covers current ideas in cognitive science, the novice-expert dimension, the teaching of medicine, and a potentially useful model of learning. The research was thus an intervention study which attempted to apply some of these ideas to clinical instruction for final year medical students in paediatric cardiology. Both quantitative and qualitative analytical procedures were used. The results provided confidence that the methods used were satisfactory, and that the teaching intervention provided measurable change in the students in becoming more expert-like in their management of diagnoses.

Basic Ideas in Cognitive Science

The field of cognitive science has its origins in the work of people such as Bartlett (1932, 1958), De Groot (1965), Chase and Simon (1973), and others. Simon (1980), one of the major contributors to the field, describes cognitive science as "...the domain of inquiry that seeks to understand intelligent systems and the nature of intelligence" (p. 35). This field is beginning to have implications for education in so far as it can contribute to a theory of learning and can specify conditions which may optimize learning.

One of the basic ideas in cognitive science is that information stored in memory has a structure. The construct of knowledge structures is similar to that schemes or schemata (Rumelhart and Ortony, 1977). Knowledge structures exist for generalized concepts which represent facts and events. According to Rumelhart and Ortony (1977), schemata are data structures for representing the generic

concepts stored in memory. For Nelson (1977), a schema is an event sequence. Braune and Foshay (1983) state that:

> If a configuration of relations in a stimulus is recognized as familiar (meaningful), then the whole configuration consisting of as many parts as there are relations, can be represented in memory by a single chunk. This chunk can be utilised in the judgement and decision making process (p. 130).

Thus the basic premise is that knowledge is stored in long term memory in the form of chunks, which are envisaged as consisting of clusters of concepts, related to one another by meaningful links. Furthermore, knowledge is actively constructed by individuals as they attempt to make sense of the world. Knowledge has meaning for the individual in so far as it serves this purpose and exists in some rational relationship to the learner's prior knowledge. Active construction of personal knowledge by individuals is therefore seen as different from passively acquired, memorized information. While the latter may well serve many purposes (eg remembering telephone numbers or in mnemonics), it is not useful in understanding, explaining, nor in predicting. The epistemological event of truly knowing is served by the acquisition of knowledge that is coherent, parsimonious, and useful for the learner.

The Novice-Expert Dimension

The notion of organized knowledge existing in memory in the form of chunks begins to have important implications for understanding how experts operate. The early work on chess players (DeGroot, 1965) and subsequent work by Chase and Simon,(1973), Larkin et al, (1980) describes the difference between experts and novices as a difference in the way the knowledge is organized in memory. For experts, the relevant knowledge is well organized into structured chunks, whereas this is not the case for novices i.e., the internal knowledge structures are

different for experts and novices, and this is more critical than differences in amount of knowledge. Experts can be said to use chunked procedures, and expertise has more to do with better knowledge organization and mechanisms for accessing the chunked knowledge than with simply knowing more.

What characterizes the skill of experts?. In genetics, experts are reviewed by Smith and Good (1984) as using a forward working approach; making frequent checks on correctness; using an accurate and detailed book-keeping approach; using a broad range of heuristics, and investing initial time in qualitative analysis of the problem, which serves as a basis for planning the problem solving strategy. This last strategy is also referred to as elaborative reasoning by Freeland and Larkin (1985) and Coles (1985), and as redesription by Reif,(1983). Expert knowledge is thus more hierarchically arranged and organized into larger functional chunks. In contrast, novices tend to access knowledge in a piecemeal way, and use more algorithmic approaches (i.e. a plug-in-the-formula approach).

The field of medicine appears to have stimulated a considerable amount of research motivated by cognitive science. The production of artificial intelligence programs such as MYCIN and SHRINK indicate the vast amount of human potential that has been invested in this area. Of considerable interest is the research that is concerned with the difference between novices and experts, and the changes that occur when a novice becomes an expert. Medicine provides a rich field in which to carry out these investigations. Since it is an applied field, the main aim of medical teaching is for higher order thinking which is an active and sustained effort directed at solving a complex problem requiring a combination of factual knowledge and problem solving strategies. The difference between medical students (novices) and physicians (experts) has been investigated by researchers

such as Elstein et al, (1978); Feltovich, (1981); Kolodner, (1983); Patel and Frederickson, (1984); Barrows et al, (1978); Bordage and Zacks, (1984); Gale and Marsden, (1983).

Feltovich (1981) states that experts in medicine establish, over time, a large "vocabulary" of memory structures each representing a recurring problem solving strategy which can be used to make sense of subsequent problems. Their knowledge structures are said to be chunked, arranged hierarchically, and embedded within more general knowledge representations and " expertise is largely a matter of the content and organization of knowledge in long-term-memory, and mechanisms for engaging appropriate knowledge in situations where it is needed" (Feltovich, 1981, p.11). Elstein et al (1978) found that experts have improved "accuracy of interpretation", and Barrows et al (1978) found that the hypotheses generated by experts are qualitatively different from those of novices.

Feltovich's (1981) findings on the differences between experts and novices knowledge can be summarized as follows:
The knowledge base of novices is classically centred, i.e. it focuses around classical textbook structures: It is sparse, i.e. it lacks extensive cross-referencing and connections: It is imprecise, i.e. it is overgeneralized, undifferentiated, and sometimes inappropriately specific. On the other hand, expert knowledge is extended, i.e. it includes disease categories and disease variants in chunks; It is dense, i.e. it has extensive cross-references and connectedness; it is precise, i.e. it is well differentiated and is neither too tolerant nor too restrictive.

If experts have different internal structures of memory representation, how does this happen?. Bascones and Novak (1985) suggest it is due to a "natural ability (or proclivity) to organize knowledge into meaningful frameworks", i.e. some individuals do this spontaneously. The question arises of whether or not this can be taught. Of particular interest are research studies that investigate the factors involved in the transition between novices and experts. Kolodner (1983) focusses on the role of experience, and claims that "experience serves to turn unrelated facts into expert knowledge" (p.498). This claim may seem to be rather obvious, but the mechanism by which this happens is the point of interest. Her study on the role of experience in turning facts into expert knowledge was done using artificial intelligence. The result of this study was a computer program that learns from its own experiences and attempts to be closer to the way in which humans learn than the rule-based expert systems such as MYCIN. This research is still in its infancy, but it has the promise of being one way in which to approach the issue of how experience affects the development of expertise.

Learning and Teaching

Resnick (1983) claims that cognitive science is leading to a new consensus on the nature of learning. To summarize this viewpoint, it is held that learners construct their own understanding of their world; learners understand facts and events by knowing the relationships that connect them; learning new knowledge is contiguous with the learners prior knowledge. According to Resnick (1983), research in cognitive science "...is shaping a theory of learning in which the content of what is being learned plays a central role" (p. 478). This is in contrast to recent views of intelligent performance as a system of processes of thinking. Furthermore, cognitive scientists have recognized that "in order to understand

complex learning, they must study how people learn particular subject matters" (Resnick, 1983, p. 478). It is therefore not surprising to find in-depth cognitive science research studies in a variety of disciplines such as physics (eg. Clement, 1979; Di Sessa, 1982; Larkin, 1980), mathematics (eg. Geeslin and Shavelson, 1975; Resnick,1976), language (Rumelhart, 1975; Schank,1972), genetics (eg. Smith and Good 1983; Collins, 1986) and medicine (eg. Rippey and Voytovich 1983; Braune and Foshay,1983; Patel and Groen, 1985; Norman et al ,1979).

In the process of learning, the acquisition of concepts and principles is insufficient for effective use (e.g. in problem solving) if this knowledge is not appropriately organized (Reif, 1983). Consequently the challenge in teaching can be seen as facilitating the way in which the students organize their store of knowledge so that they develop knowledge structures which can be easily accessed and which can assimilate new information appropriately and efficiently. (Abercrombie, 1969; Larkin, 1980; Reif, 1983).

Teaching Medicine

The current dissatisfaction with the education and training of medical doctors focusses on the fact that medical students are expected to learn ever-increasing amounts of knowledge in ways that favour passive reception learning. As medical discoveries increase, the medical faculty respond by packing more topics into their lectures, cutting back on laboratory classes and independent study time to make way for yet more lectures. This fosters memorization and passivity instead of enquiring minds, well prepared to keep up in a rapidly changing discipline (Bok, 1984). In answer to the question of why medical education has changed so little in the face of persistent criticism, Bok (1984) suggests that teaching has a low

priority within medical schools, and that success in medical research carries far greater reward for the faculty. It is also possible that until recently, the field of education has been unable to make significant contributions to teaching in the disciplines through not having well formulated learning theories. With the demise of the behaviourist tradition, there are indications that cognitive psychology, and more specifically, cognitive science may be able to offer some help to the practice of educating in all the disciplines. The field of medicine stands to gain significantly, especially as much work in cognitive science deals with medical topics.

One answer to the crisis in medical education has been the formulation of the GPEP Report by the Association of American Medical Colleges (1984). This report contains numerous excellent aims for medical education which, if put into effect, would serve to improve the situation in general. One relevant example, Conclusion 4, Recommendation 5 suggests that "Medical faculties should specify the clinical knowledge, skills, values and attitudes that students should develop and acquire during their clinical education". It is pointed out, however, that faculty members rarely achieve consensus on what exactly these should be. One important aspect of clinical knowledge concerns the way in which it is organized in the minds of expert clinicians. This study deals with the topic of appropriate knowledge organization and the implications of this for teaching medicine.

In the light of the discussion on the developments within cognitive science, we seek to find out whether medical students would improve in their ability to solve complex problems (i.e. diagnose) efficiently if they were helped to understand that knowledge can be viewed as having structured organization, and that different organizations are appropriate for different purposes. For example, an

understanding of basic scientific knowledge involves different structures from those required in medical diagnosis. We consider such information to be an agendum on the "hidden curriculum" of medical schools, and suggest that there is a need to make some of the hidden curriculum in the field of medicine more apparent. By "hidden curriculum" we are referring to the large amounts of tacit knowledge acquired by experts without conscious awareness, which is essential to good performance. This tacit knowledge is often substantial, subtle, and difficult to make explicit. It constitutes patterns of information which are regarded as existing in the mind in the form of chunks. It is the existence of these chunks that characterizes expert thinking (Reif, 1983).

A Model of Learning as Conceptual Change

From an epistemological point of view, one of the purposes of knowledge is to explain and predict facts and events and to impose order on a disorderly world. The constructivist view of learning holds that individuals are committed to making sense of the world, and do so by actively constructing knowledge in the process of understanding. In order to do this, individuals have to start with their existing knowledge which then becomes changed . One learning model that is emerging from the constructivist tradition views learning as a process involving conceptual change (Posner et al, 1982; Hewson,P.W., 1981). This model of learning is based on selected theories from the philosophy of science (Kuhn, 1970; Toulmin, 1972; Lakatos, 1974), and from the cognitive view of education (Ausubel, 1968; Novak, 1977).

The model views the individual embarking on a learning experience as having a certain amount of existing knowledge which is relevant to the topic. If learning

takes place, the individual initially realizes that the existing knowledge is no longer adequate to explain or account for a new situation. The learner thus experiences dissatisfaction with the existing knowledge. In order to make sense of the new information, the learner's existing knowledge needs to change. The change that occurs may be the integration of further new information with the old; it may be a differentiation of the old into more refined or exact conceptions; it may be an exchange of old conceptions for different, new ones. If an individual becomes willing to change his or her existing conceptions, it is likely to be because the new conceptions are more credible than the old. More specifically, the model states that the new conceptions need to be experienced as more intelligible, more plausible and more fruitful than the old, and outlines the possible mechanics of how this would operate in a learner's mind. Intelligibility refers to understanding or knowing something as logically coherent, but not necessarily true. Plausibility refers to understanding or knowing something which is logically coherent and also realistic or true. Finally, the term fruitful is applied to knowledge which is both intelligible and plausible, and also serves to enhance understanding, thereby meeting epistemological criteria of prediction, explanation, and parsimony.

The specifications for learning contributed by this model of learning raise interesting and potentially powerful implications for teaching. If instructors know what the existing conceptions of the students are, well planned instructional strategies (integration, differentiation, and exchange) can be designed to maximize student learning. While the validation of the model in the classroom setting is still in its early stages there have been some encouraging

results which indicate the potential of the model Hewson, M.G. and Hewson, P.W., 1983, Hewson, P.W., 1984).

Effective Knowledge Organization

We have suggested that the challenge of education is to help students appreciate that well organized knowledge is fundamental to proper learning, and is characteristic of the way in which experts think. The task of this research project was to take final year medical students who should theoretically have all the medical facts they are expected to know, and show them how it may be organized effectively.

Novak et al (1980, 1983) found that students improve in their understanding of science when they use a simple organizational model of knowing. This serves to provide relationships between hierarchically organized ideas (concepts, theories and principles) as well as relationships between ideas and actions (doing tests, transforming data, and making knowledge claims). Through long hours of discussion in which the concepts of education were merged with the concepts of medicine, we managed to agree on a simple model of selected aspects of medicine. This served as the organizational principle which was used to represent medical knowledge in this study and is referred to as a medical conceptual model (MCM).

The question of what constitutes appropriately organized medical knowledge has been addressed in earlier papers by the authors (Kriel and Hewson, in press; Kriel, Hewson, Zietsman, and Levin, in preparation). In these papers we argue, with justification from the literature, that information stored in the memory of medical experts (clinicians) is probably organized around the construct of "clinical pictures" or "clinical patterns", and that pathological, and aetiological concepts

are related to these clinical constructs. The relationship between these categories of concepts is complex. The categories and their inter-relationships are depicted in figure 1.

Fig.1 ABOUT HERE

In the process of clinical diagnosis, the recognition of a clinical pattern is postulated to be the starting point for the clinician. These clinical patterns are constructs developed as a result of experience. They are not disease-specific in that there is not a one-to-one relationship between the clinical presentations and the underlying pathology or pathophysiology. Indeed some diseases (eg renal disease) have a number of histo-pathologies that do not have a single clinical presentation but may present in a variety of clinical patterns. Conversely, certain clinical pictures (eg the nephrotic syndrome) may show a variety of histo-pathological findings. The clinical pattern is an instance of chunked information which is operative in the diagnostic process.

After recognizing the clinical pattern, the clinician attempts to identify the pathology or pathophysiological processes which underly the clinical findings. They may also exist as patterns, i.e. complex inter-relationships between a variety of pathologies and pathophysiologies. The aetiological level comprises the agents and/or processes which cause the pathologies and pathophysiologies. There are thus three levels of clinical thinking, (or three categories of medical concepts); the clinical level, the pathological/pathophysiological level, and the aetiological level, and the relationships between them are multiple and complex.

When a clinician makes a diagnosis, it is important to realize that he or she usually does not recognize a disease. Black (1972) writes: "Even when we think

we recognize a specific disease such as 'acute nephritis' we are really recognising a syndrome, and brief reflection reminds us of other disorders... which can duplicate the clinical picture". A diagnosis can be said to be a brief summary of the information in one or more of the three levels. A diagnosis can be viewed as not so much a disease entity as a construct, i.e. a label providing information about the pathology/pathophysiology, the aetiology, and the clinical picture. For example, the diagnosis acute glomerulonephritis is a summary for the following:

a. The clinical picture is acute nephritis;

b. The underlying pathology is acute proliferative glomerulonephritis;

c. The aetiology is an antecedent streptococcal infection (assumed).

While there are obviously many more medical categories that are considered in clinical diagnosis, we have decided to limit our discussion to those described above. Other aspects such as data collection, (from histories to ECG), prognosis etc. can be seen in relation to these three levels. Other factors (eg psychological, and probablistic) are certainly important, but are outside the scope of this study.

Conceptual networks were drawn up, by Kriel and Hewson, in collaboration with the expert paediatric cardiologist, Levin, for Cyanotic and Acyanotic Congenital Heart Disease. The networks are organised in terms of the three levels shown in Figure 1. (ie clinical and pathological/pathophysiological levels. The aetiological level is not useful in CHD as causal agents are mostly unknown.). The conceptual networks produced by the authors are shown in Figures 2 and 3. These are not considered as absolute or fixed. They simply represent one way of viewing these topics, and serve as a potentially useful way of organising medical knowledge for the purpose of making clinical diagnoses.

FIGURES 1 AND 2 ABOUT HERE

Medical Text Books

A careful analysis of the most commonly used textbooks in medical schools such as the University of the Witwatersrand shows that the medical concepts are organized according to pathological and pathophysiological categories. This can be termed classical knowledge organization, which is a logical but encyclopaedic way of looking at the discipline. Taylor (1976) refers to classical knowledge structures as opposed to task structures (ie diagnostically appropriate knowledge organization). It is more than likely that most pre-clinical, and many clinical lectures have this classical organization. The assumption in many medical schools is that the more knowledge that can be memorised, the more proficient students become and the better they will be in applying that knowledge. There are, however, a few clinical textbooks that are now attempting to organize medical knowledge in a diagnostically appropriate way eg The Principles and Practice of Medicine (Harvey et al, 1984; Harrison's Principles of Internal Medicine, Petersdorff et al, 1983). However this style is not applied consistently throughout the textbooks and the organizing principle is never made explicit. This variation of style may lead to confusion in the mind of the student when comparing the information with that obtained from other textbooks. This is the basis of an argument (Kriel and Hewson, in press) that a distinction should be made between textbooks for reference purposes and those written for teaching purposes.

Summary

It is our contention that the organization of knowledge in the minds of medical experts is different from this classical organization, and may be described as

consisting of chunks which are diagnostically appropriate. Furthermore, the value of getting experience as practising clinicians is probably the effective reorganization of knowledge structures. It is this reorganization that has to take place before the novice medical student can become an expert clinician.

The position we are taking here is reflected in the recent Gregg Memorial lecture by Shapiro (1986) who wrote that:

> Our accumulated knowledge is organized and applied differently when we are exploring immediate solutions to a problem as opposed to developing fundamental comprehension of a particular biological subsystem. It is important for both medical scientists and medical practioners to understand and respect these differences and to find some way to deal constructively with each other's concerns (p 83).

We have argued that these organizational differences are visible in the various ways in which knowledge in medical textbooks is presented (Kriel and Hewson, in press). More specifically, the textbook organization of medical knowledge is often the reciprocal of the knowledge organization in the minds of expert clinicians.

Our aim in this study is to answer the question: Can the reorganization of knowledge structures acquired from pre-clinical lectures and from textbooks be mediated by the instructional process in medical school, rather than waiting for it to occur in an idiosyncratic way in the lengthy process of getting medical experience?

The research reported in this study attempts to investigate the way in which we can facilitate the novice-expert change in final year medical students in the area of paediatric cardiology. The instruction that takes place is based on the conceptual change model of learning. The tasks we used to investigate knowledge structures used in diagnosis are taken from the Feltovich (1981) study, but the

criteria used to distinguish experts from novices are slightly different from those used by Feltovich (1981). They are as follows:

1. Is the diagnosis correct?
2. What kind of structures are used?
3. Are the concepts linked?
4. Are only relevant concepts used?

HYPOTHESIS

If students are given instruction which explicitly helps them to think about medicine as experts do (i.e. they are helped to conceptualize knowledge as consisting of parts which are related in a variety of ways, and which can be regarded as chunks), and

... if students are instructed in such a way that they can understand that knowledge is organized in different ways for different purposes, and that the classical structure of text book organization differs from the task organization of knowledge required for diagnosis,

... then they will perform more like experts in the diagnosis of relevant medical cases.

PROCEDURE

This study is investigatory in nature. A pre-test/post-test control group design was used, but more weight was given to the qualitative results than to statistical analyses of differences between the groups.

The students involved in the study were 6th year medical students (i.e. pre- MD) who were currently involved in their final rotation (paediatric cardiology), at the University of the Witwatersrand, South Africa. The control group (N=11) had just completed the rotation, while the experimental group (N=12) had just started. The rotation was supervised by Professor S. Levin, a paediatric cardiologist.

Experimental Group

The 12 students were identified by a code number, E1-E12. The group comprised 3 women and 9 men. The average mark for the previous year for this group was 65.41%, (SD= 3.71). The group was considered as average by the professor.

Control Group

The 11 students were identified by a code number, C1-C12 (C11 did not take the tests). The group comprised 5 women and 6 men. The average mark for the group for the previous year was 67.60%, (SD=4.82). The group was considered to be slightly above average by the professor. Students C6 and C9 both had excellent average marks of more than 70% for the previous year, and C10 had been awarded a Rhodes Scholarship for the forthcoming year.

Expert Performance

To ensure that our analysis strategy was able to discriminate between experts and novices, we also tested our expert paediatric cardiologist.

TESTS

Case Histories

Documented case histories in paediatric cardiology developed by Feltovich (1981) were selected for use in this study. These cases were originally designed to show the differences between novices and experts in clinical diagnosis. Each case history lists the clinical signs and symptoms and the laboratory tests (usually X-ray and EKG) that were observed in real patients and recorded in their medical records. These cases were used to allow the investigator to compare the performances of subjects (the medical students) in a uniform stimulus environment. Thus the order and content of patient findings in the case studies was fixed. Careful screening and checking was carried out on these case studies by Feltovich and his medical colleagues, and any troublesome distractions and artifacts from the cases were removed. In some cases, however, data were added to the cases (in consultation with the medical experts) in order to provide suitably clearcases for the purpose of the Feltovich study. In this study, the students were asked to diagnose the cases by "thinking aloud". The instructions were read aloud by the investigator. The students were asked to report any thoughts they may have had in formulating a diagnosis of the patient's condition. They were asked to work through the cases item by item, and were allowed to review items whenever necessary. At four points in each case, the students were asked to report on any "hunches" he or she might have had about the patient's condition. The sessions were tape recorded and subsequently transcribed verbatim. The cases used in this study are given in Appendix B, and were as follows:

Pretest

Experimental Group

Case 1: Discrete Membranous Subaortic Stenosis

Post test

Experimental Group and Control Group

Case 4: Pulmonary Atresia

Case 5: Coarctation of the Aorta and Bicuspid Aortic Valve and Mitral Insufficiency

ANALYSIS METHODOLOGY

Formation of Conceptual Profiles

The transcripts were analysed for the concepts and the relationships between the concepts that were present in the minds of the students as elicited by these cases. This was done using a technique developed previously (Hewson, 1982, 1985). This involved reading through the each transcript very carefully, and identifying each concept mentioned by the student. Each of the concepts was labelled in order to show: 1. whether the student was actively considering it as contributing to the diagnosis, (signified by a + symbol); 2. whether the student was actively refuting the concept as contributing to the diagnosis, (signified by a - symbol); or 3. Whether the student mentioned a concept but was unsure of its relevance for the diagnosis, (signified by a ? symbol). Appendix A shows a verbatim transcript of the diagnostic interview for Case 1, with the summarised Conceptual Profile.

The Conceptual Profile for each student was represented on a standardised conceptual network or template for this area of medicine. The templates were based on the networks shown in Figures 2 and 3. This procedure made it possible to analyse the profiles in terms of the stated criteria, as well as making it possible to compare the profiles compiled for the same students by different

authors. Since the transcripts were analysed separately by three authors (Hewson, Kriel and Zietsman), consistency in the analyses was checked and differences were ironed out through meticulous re-analysis of the verbatim transcripts. Each transcript was thus analysed 4 or 5 times. Appendix C shows a completed template for student E6. The template technique has been used previously (Hewson, 1982; Hewson, and Hamlyn, 1985) with useful results.

Analysis of the Conceptual Profiles

The conceptual profiles for each student on the cases 1, 4 and 5 were analyzed using the criteria discussed previously. These criteria are:

1. Diagnosis a. correct, b.nearly correct or included in differential diagnosis, c. incorrect.

2. Knowledge organization and strategy a.construction of scheme, b.combination of scheme construction and list elimination, c. elimination from lists, d. unclassifiable.

3. Concept organization a.connected concepts, b. unconnected concepts, c. unclassifiable.

4. Type of concepts a. relevant and essential, b. irrelevant and non-essential, c. unclassifiable.

(Note; The unclassifiable category exists for those scripts that do not lend themselves to the analysis.)

While the data were used for simple statistical analyses, the more detailed ethnographic analyses of the differences between different students' performance (i.e. between the Control and Experimental groups) and between

students' performance on the pre and post tests (Experimental group only) were explored.

Finally, the students' responses to a questionnaire on their opinions concerning this intervention study are presented.

Teaching Intervention

The teaching intervention took the form of lunch time seminars over a period of 6 weeks. Attendance was voluntary. The seminars were somewhat experimental, but they were planned with the Conceptual Change Model (CCM) in mind. A pilot teaching series was held with 4th year medical earlier in the year. The pilot run was encouraging and enabled us to adjust the series more appropriately to the medical students.

The 6 seminars are desribed briefly. Each seminar is analysed in terms of it's intent with respect to the CCM. We monitored the seminars by informally documenting the students' reactions as we perceived them, as well as taking a count of the number of students present, as it is said that medical students "vote with their feet"!

At the end of the series, we asked the students to fill in a questionnaire regarding their reactions to the seminars. As only a few complied with this request, the comments that we received are reported anecdotally.

Seminar 1

Topic: We discussed the importance of being able to arrange knowledge in the form of clusters or groups of ideas. This led to the concept of networking or mapping knowledge (see Novak et al, 1983). We discussed the importance of the

hierarchical organization of knowledge and the difference between text book and problem solving organization. The students were asked to generate their own networks on the topic of Congenital Heart Disease(CHD), without any help from us. They were divided into 3 groups for this, and they then discussed (argued) amongst themselves the merits of the different networks.

CCM Analysis: The seminar was intended to raise the students' level of dissatisfaction with their existing epistemological understanding of medical knowledge as applied to problem solving, i.e. diagnosis.

Feedback:The seminar provoked a lot of good discussion. All students present.

Seminar 2

Content: A conceptual organization of Acyanotic CHD was developed by Prof Kriel for the students using the organizational model illustrated in Figure 1. The students were told that the network attempted to represent the way in which an expert would think on the job, and that we had produced the network with the help and concurrence of the paediatric cardiology lecturer, Prof Levin. It was emphasized that the network is not a diagnostic procedure. Rather it is a method of knowledge organization so that it is appropriate for diagnostic purposes.

CCM Analysis: Conceptual exchange of textbook organization for clinical organization of subject matter.

Feedback: The students sat silently throughout Prof Kriel's presentation, and continued sitting in this stunned silence for a while. We found this disconcerting, but later on the students became very enthusiastic. Their comments included: "If our professors think this way, why don't they teach this way?. It would make learning so much easier".
All students present.

Seminar 3

Content:The students were asked to use our scheme to draw up networks on the topic of Arrhythmias, which they did in groups of 3 or 4. Each of their networks was discussed and Prof Kriel worked on their ideas and reformulated them into a network using the three levels illustrated in Figure 1. Student discussion followed.

CCM Analysis: Further differentiation of the ideas presented in seminar 2. The hierarchical levels (Clinical, Pathological/Pathophysiological, Aetiological) were integrated into the general ideas of network formation.

Feedback: Some students who already had a well worked out system of manipulating knowledge did not appear to be so enthusiatic about our networks. Their system seemed to involve learning the textbook organization and using the "elimination from a list" strategy in clinical diagnosis. For these students, our networking strategy was probably intelligible and plausible but not fruitful as

they were reluctant to exchange their existing system. One student in particular (E4) felt this way. Most of the students who had no existing system of organizing their knowledge found the approach useful (fruitful), as well as intelligible and plausible.
Eleven students present.

Seminar 4

Topic: A presentation of Black's (1972) version of Renal Disease. The clinical approach suggested by Black was explained in the context of the three levels.

CCM Analysis: Further differentiation of the ideas by applying them to a different topic.

Feedback: The students were enthusiastic and discussed freely. They concurred with this organization of knowledge for Renal Disease and said that the approach would be useful in the topic of Viral Diseases. One student (E3) stated that our strategy "was a better way of learning rather than loading their minds with lists". However E4 restated that he prefered to memorize everything (using lists) for exam purposes. All students present.

Seminar 5

Topic: A presentation of the epistemology of the knowledge organization we were suggesting to the students. This was done in a question and answer style discussion, using the topic of Murmurs as an example.

CCM Analysis:The hierarchical levels discussed earlier were further differentiated.

Feedback: It was anticipated that this topic would not be an easy one as it is more epistemological than medical. The students appeared interested and agreed with the ideas. All students present.

Seminar 6

Topic:The application of the networking strategy was shown using the topic of Cyanotic CHD. The students were asked to recall a recent case they had seen with this condition, and to impose the relevant concepts on the network.

CCM Analysis: Integration of detailed clinical information with the network strategy.

Feedback:The students laughed with pleasure as they could see how well the case could be imposed on the network. It was apparent that this strategy was intelligible, plausible and fruitful to these students. Seven students present.

RESULTS

Case Diagnosis Analyses

The quantitative results of the analyses are presented in Tables 1, 2 and 3. The qualitative analyses are summarized in Tables 4, 5, and 6. A detailed example of the development of a Conceptual Profile for one of the students is given in Appendix B. Detailed analyses of one student responses using the conceptual template are given in Appendix C.

Analysis of the pre- and posttest data of the experimental group.

Table 1 gives the analyses of the performance of the 12 students in the experimental group on Cases 1 & 4, and 4 & 5. The data are presented as frequencies, i.e. the number of students who were categorized into each criterion. In order to compare the frequencies, the pretest frequencies in Case 1 were compared with frequencies of Cases 4 and 5 respectively. A Fisher Exact Probability Test was performed on these data to find out if there was a statistically significant difference between the performance of the Experimental group before and after the intervention. As the Fisher Exact Probability Test requires 2X2 contingency tables, the criteria were collapsed into appropriate categories.

From these calculations it can be seen that the number of correct or nearly correct diagnoses did improve in both the Cases 4 & 5 , but not significantly (Case 4, $p=0.106$ N.S., Case 5, $p=0.108$, NS). This was a disappointing result, and it leads to queries concerning the ability to think like experts being linked with the ability to diagnose correctly. It also raises the question of whether the

intervention was sufficiently extensive to cause a dramatic change in this criterion.

The use of clustered knowledge in the form of schemes/construction rather than using lists from which pathologies are eliminated was improved in the post-test in Case 5 (p=0.045 *), but not in Case 4 (p=0.245 NS).

The use of linked or connected concepts rather than unconnected idiosyncratic concepts improved significantly in both Cases 4 & 5 (p=0.025 *, and p=0.017 * respectively). In addition the post test data show that the students in the experimental group tended to use more essential or relevant concepts in Case 5 rather than contributing a wide range of non-essential or nonrelevant concepts to the diagnosis (p=0.013 *).

In general there was more significant improvement in the way the students appeared to have organized their knowledge in Case 5. This may have been a reflection of the fact that the pretest Case 1 was the same knowledge domain as Case 5. It is more likely, however, that the reason is that Case 4 (Cyanotic CHD) is commonly remembered using a mnemonic (The 5 Ts) and this would have shown in our analyses in this way. The qualitative analyses of the expert performance (Table 6) also show this.

Analysis of the control and experimental data for Cases 4 and 5.

Table 2 shows the frequencies of students in both groups' responses on the 4 criteria for Cases 4 and 5. There was significant improvement of the experimental group on the construction of schemes, the use of linked or connected concepts, and the use of essential, relevant concepts in the diagnosis, The improvements were

greater in Case 5 than in Case 4, and the reasons are likely to be the same as in the comparisons between the pre- and posttest scores for the experimental group ie the difference between the two cases, or the possibility that the pretest was similar domain knowledge to Case 5.

Analysis of the experimental group pretest data (Case 1) with the control group posttest data (Cases 4 & 5)

Table 3 shows these comparisons, and shows that the groups were not different in the way their knowledge was organized, as evidenced by their performance on these tasks. This was expected since neither group had been exposed to our ideas. The significant difference in diagnostic correctness for the control group in Case 4 is surprising. However in every comparison between Case 1 and Case 4, or Case 5 and Case 4,

there are more correct diagnoses in Case 4 regardless of whether it is the experimental or control group (See Table 1 and Table 2). This suggests that Case 4 was easier to diagnose than Cases 1 or 5.

Summary of Qualitative Analyses

These data indicate that the instructional intervention served to change the way in which the students organized their knowledge, as evidenced by their performance on the diagnoses of the cases. While these changes were not dramatic, they provided confidence that some change for the better had taken place. The similarity between the experimental pretest and control group data provided confidence that these changes could be attributed to the intervention concerning appropriate knowledge organization, and the use of the model of learning as conceptual change as a means of doing this.

The lack of change in ability to diagnose correctly raises questions concerning the theoretical connections of appropriate knowledge organization and accurate diagnoses, or the methodological issues of length of intervention, the diagnostic tasks or the methodology used.

Qualitative analysis

A more detailed analysis of student responses is given in Tables 4, 5, and 6.

The pretest and posttest data for the experimental group are given in Table 4. This shows a summary of the 12 students' performances on Cases 1, 4 and 5. Table 5 shows similar detailed analyses for the control group on Cases 4 and 5.This information is useful to the extent that it serves to provide descriptions of student performance without the teaching intervention. Table 6 shows the performance of the expert cardiologist on the 3 diagnostic tasks.

These data are discussed further in terms of the 4 criteria used in the analysis.

Diagnostic Accuracy

Of the students showing improvement, the greatest change was in students E1, and E8. In each, the performance on both cases was improved with a correct diagnosis as well as improved use of schemes, linked concepts and essential concepts.

A close inspection of the student performance in the control group and the pretest experimental group shows that those who reached a correct or nearly correct diagnosis did so by using some sort of knowledge scheme of their own (C3 in Cases 4 and 5, C5 in Cases 4 and 5, E11 in Case 1, and E12 in Case 1).

A control group student C12 reached a nearly correct diagnosis in Case 5 using lists /elimination, but seemed to feel very uneasy, as in the following extract:

"My hunch now is that it is a physiological murmur or a L to R shunt"(9). "Maybe this was set out to con... There seems nothing to suggest anything"(10). "I'd think of a coarctation... But I'm not sure why it should present now, unless it's a coarctation due to a tumour or something. Um..or an error. Or I'm missing something"(13). And later on- "That makes me think that there's an AS with a click, valvar... and perhaps an MI... I think I've missed a lot"(20). "I think I'm probably entirely wrong. I can't discount the fact that I thought it was a.... coarctation"(HPE). "Phew!...I'm all confused now, because LA enlargement...I mean, then I think of something like mitral stenosis which doesn't fit anyway. I'd thought of MI if anything. Um...LV enlargement would fit. 'Prominent pulmonary vasculature'?...I don't know where the shunt is. I don't know!...At this stage I'm lost" (22).

Organization of Knowledge

Lists/elimination

Many students in the control group and in the pretest of the experimental seemed to have stored their knowledge in the form of lists. Their problem solving strategy then involved eliminating items from lists. An example of a student using the list/elimination technique, is found in the control group, student C8:

"Well I presume that this is a cyanotic CHD, and there are various cyanotic CHD's you can consider. The way I always remember them is the 5 T's: Tetralogy of Fallot, TA, TAPVD, TGV, and...I can't remember, I think there's another one. But the most common is the Tetralogy of Fallot"(C8, Case 4, HH).

The strategy of reciting a list of cyanotic CHD was used by many students in the control group. The point is that these students were thinking primarily in terms of the classic textbook organization of the pathologies and then attempting to fit these to the given clinical symptoms.

Many students used the lists/ elimination strategy, or a combination of lists/elimination with schemes/construction. The use of unconnected concepts

appears linked with the use of lists/elimination, as is expected (eg. C1,Case 4;C2,Cases 475). The occurence of non-relevant concepts is also prevalent with the students who used the list/elimination strategy (eg.C4,C8, C9, and C10 in both Cases 4&5).

Schemes/construction

Students in the experimental group were prepared to use more qualitative reasoning, making greater use of clinical data and the organizational scheme that had been suggested to them. For example:

"I should have gone on to the obstructive side which is confirmed by the absence of pulmonary plethora. In terms of the obstructive side, you have got to divide it into those with RV hypertrophy and those with RV hyperplasia. And then it could be either with or without VSD... It's the pulmonary flow tract obstruction. There is also tricuspid atresia, which is also...but then that would present with a L axis on the ECG. So this is not a tricuspid atresia."(18). "At the moment I'm thinking of CHD, an obstructive picture, which seems to be a hypoplastic RV. That will be my final diagnosis"(E12,Case 4,HF).

While E12 's final diagnosis was nearly correct, his thinking pattern brought him close to the correct diagnosis (pulmonary atresia). He used the scheme as an organizing principle, and added more clinical concepts than we had originally suggested.

Similarly, E1, Case 4 used our scheme to his advantage and apparently felt more confident that his diagnosis was approximately correct:

"Well, when I see the pulmonary vasculature diminished, I know automatically that I'm on the right side, and I'm going for the (correct) diagnosis. I feel better already!" (17).

A good example of a student using schemes/construction in Case 5 is student E5:

"So this lesion hasn't been severe enough to compromise his growth...um...But because he is less active my thoughts turn now to some form of obstructive acyanotic lesion"(7). "OK, there's a discrepancy between the left arm and right arm, right leg, and this immediately brings me to a possible diagnosis of coarctation"(12).

Three of the experimental group showed little change (E3, E5, E11) as these students were already using some kind of knowledge organization before the teaching intervention, as observed in the pretest (Case 1). However E4 also showed little change after the teaching intervention, and continued to use lists/elimination, with rather unconnected concepts and many non-essential concepts. It will be remembered that this student was particularly resistant to the ideas being presented in the seminars.

A close inspection of the control and experimental pretest transcripts shows that the students who reached a correct or nearly correct diagnosis also used some knowledge organization systems of their own (eg. C3, Cases 4 and 5; C5, Cases 4 and 5; E11, Case 1; E12, Case 1). In addition, it can be seen that the list/elimination strategy also produced some correct or nearly correct diagnoses (eg. C2,Cases 4 and 5; C4,Cases 4 and 5; C6,Case 5; C7,Case 5; C8,Case 5). Of course this is not surprising as it is probably the strategy used by most novice physicians and we know that they are able to diagnose adequately much of the time. The issue is whether or not their thinking is as efficient and organized as experts.

Connected concepts

This criterion is closely linked to the previous criterion of knowledge organization, and most students who used schemes/construction strategy also had connected concepts. There were indications, however that a number of students in

the control and pretest experimental groups were making attempts to link their concepts In these cases the students used their own schemes, and got "nearly correct" diagnoses For example, in C3, Case 4, we find concern with whether there is L or R-sided failure (12&16); whether there is L or R-sided cardiomegaly (17); whether there is an obstruction or valve pathology (14,16,717). This student used good clinical reasoning, but his scheme seemed different from ours. He also had a tendency to use lists at the beginning (1), and did not reach a correct diagnosis. Student responses such as these gave us some ideas for a better knowledge organization of cyanotic CHD.

Relevant concepts

Of considerable interest was the tendency of certain students to distract themselves with non-relevant and non-essential concepts. These concepts were triggered by the items in the cases, and the students felt compelled to digress on their importance in general, thus losing track of their argument. About 9 of the control group did this, compared with 4 in the posttest experimental group. An example is C4,Case 4 where the cyanotic CHD was identified early, but at various points in the case, acyanotic CHD pathologies were considered, i.e. PDA (8,11), coarctation (8,10,14), AS (14). In addition rare pathologies were considered such as Ebsteins (HF), Eisenmengers (17,HXR,18), and tricuspid stenosis (1).This student used lists of pathologies and elimination strategies.

In the experimental group, E4 was an example of students using non-relevant concepts. In Case 1 (subaortic stenosis) he considered; ASD, VSD, PDA, coarctation, PS, ostium primum, ostium secundum, ECD, valvar AS, supra valvar AS, subvalvar AS, peripheral PS, infundibular PS, unfolding aorta, mitral or

tricuspid valve lesion, also R to L shunts, specifically, TGV, and a combination of R to L shunt and ASD in his final differential diagnosis (!). As mentioned earlier, E4 was reluctant to stop using memorized lists. He was also a high scorer on the examination, and it can be suspected that the memorization strategy proved a successful way of scoring well in the multiple choice exams in medical school. This data serves to query the effectiveness of such examinations for medical students whose ultimate taskis to be able to diagnose patients' illnesses.

Analysis of the expert/novice performance

The data in Table 6 show that the expert performance on the CTA analyses differed from most of the experimental group performance on Case 1 (in Table 3), and the control group on Cases 4, and 5 (in Table 4). The expert, not surprisingly, had correct diagnoses. He also used the scheme/ construction strategy, except for Case 4, where it appeared as if he may have had the 5 T's in mind. He used linked concepts and only relevant concepts were considered. The expert's performance was more similar to some of the experimental group's performances in the post test (i.e.in Cases 4 and 5). The conceptual template network analyses in Appendix C shows the consistency in expert performance. The student performance in the experimental group approximated the expert performance more closely, while that of the control group seemed markedly different. This analysis served to provide confidence in the ability of our analyses to discriminate between expert and novice performance. It also served to indicate that the teaching intervention did result in the performance of the experimental group being more like that of the expert.

Affective Responses by the Students in the Experimental Group

The recorded student comments in the seminars indicated considerable interest in our intervention study. The amazement and occasional stunned silences which led to vigorous discussion about the way in which experts teach their field was cause for satisfaction.

We asked the students to complete a questionnaire about how they liked what we had attempted to present to them. Not everyone did this (it was by now the end of the year and their final examination was close). The 5 that did respond told us that they greatly appreciated the ideas and the suggested strategy of making their medical information more clinically relevant.

1. All of the returned questionnaires indicated that the method of organizing knowledge promoted in the seminars was;

   -useful in understanding congenital heart disease (Q1).

   -intelligible, plausible, and useful (fruitful) (Q2, Q3, Q4).

2. Three of the 5 respondents were unsure that the organizing principles suggested by us could be applied to their various lecture notes, but 2 felt this was not a problem (Q5).

3. Three respondents indicated the organizing principles were useful for diagnostic purposes, while 2 were unsure (Q6, Q7, Q8).

4. All respondents thought it would be useful to get more training in the application of these ideas, and would like their lecturers to present information according to the organizing principles suggested in this study (Q9).

One unsolicited testimonial worth reporting here is the following:

"I found the programme very useful and my suggestion is that every single expert at Medical School should be introduced to this scheme of knowledge organization; and they should be 'pestered' until they also draw up a similar scheme to the one Prof Solly drew up for us. This should be introduced into their formal lectures

and, more importantly, into each clinical block during the 6th year. This scheme could be expanded to post-graduates as well, adding more refined detail to the basic scheme. I realise it is easier said than done, but one should realise that it is a long term project in which future generations of medical students will benefit greatly" E11.

One student did feel, however, that these ideas had come too late; "you can't teach old dogs new tricks"! This student, E4, was determined that his old strategy of using lists was adaquate. He was particularly distressed in the case diagnoses when he became confused and unable to reach a diagnosis. While his complaints about the un-naturalness of the simulations were acknowledged, he was the only student to complain so bitterly. We felt that he was using this complaint as a defense. It is our view, however, that 6th year students are too far on in their medical carreers to entertain radical changes in their methods of organizing their knowledge. We would prefer to do this form of intervention with students who are just embarking on the clinical stage of their training.

LIMITATIONS OF THE STUDY

The cognitive task analyses used in this study provide a constraint on the data obtained. The three cases, originally developed by Feltovich (1981), were presented to the subjects in a controlled manner, in which the clinical data presented in each case were read out item by item. There has been considerable discussion by Elstein et al (1978) and Feltovich (1981) about the validity of this diagnostic type of instrument. While these arguments will not be discussed here, there is a certain cause for concern. We felt that there were significant benefits in terms of our resources in using these cases. It would obviously not have been possible to have trained actors to simulate patients in paediatric cardiology. These carefully worked out cases provided us with a controlled stimulus

environment. We think that the method of presenting the cases to the subjects might be improved on. This would be worth investigating in a follow-up study.

A second limitation to the research concerned the timing of this intervention study. Since we elected to use Feltovich's cases, we needed students doing their rotation in paediatric cardiology at the University of the Witwatersrand. This forced us to concentrate on final year students, and the teaching intervention was done in the last quarter of the year. As mentioned earlier, we believe that this study would have been better with younger students. Our pilot run with 4th year students indicated to us that this would be a good level at which to work.

The two student groups were not matched. It might have been more valid to do so, for statistical reasons. The control group was actually above average in their grades, while the experimental group was average. We thought this might have obscured differences between the two groups with respect to improvement in the experimental group. However, both the qualitative and quantitative results showed differences that support the hypothesis of the study. While a tighter study could be designed, this one was investigatory in nature, and serves to show that the idea of teaching intervention in the novice-expert development of medical students warrants further research.

CONCLUSIONS

The Teaching Intervention

The data presented in this study serve to show that a carefully prepared teaching intervention program which was designed to help novices perform more like experts in making medical diagnoses was effective in terms of the criteria

concerning knowledge organization. The important criterion of correctness of diagnosis was improved on, but not significantly. The 3 other criteria concerning the organization of knowledge showed significant improvement i.e. the experimental group improved with respect their pretest performance, and with respect to the control group. Their performance became more expert-like. It showed their knowledge was more connected (i.e. the concepts accessed were contingent upon each other and demonstrated links to the clinical data presented in the case). Their knowledge was more parsimonious (i.e. the students began to access only those conceptions actually relevant to the case, rather than reproducing all their knowledge on the topic). Finally many of these students showed evidence of abandoning the technique of eliminating pathologies from a memorized list, in favour of constructing clinical patterns (schemes) from the information given.

Although this study was a pilot study, the teaching intervention was apparently effective in doing many of the things it was designed to do. While their diagnostic correctness was not greatly improved their thinking was more efficient, and the comments made by the students dramatically illustrated their satisfaction and enthusiasm with respect to our efforts. We do not think that the intervention was perfect. Indeed it was rather amateur and needs further development.

The Conceptual Change Model of Learning (CCM)

The potential of the CCM was demonstrated in that this ambitious intervention with final year students aimed to show them that their existing way of organizing medical knowledge could be improved. We tried to raise their dissatisfaction

levels with their existing organizations, and then to replace these with our suggested organization based on the organizing principles of a medical model, and to show that our organization was intelligible, plausible, and, moreover, useful. We felt that the students' affective response to this was most encouraging. Their cognitive responses showed their preparedness to become actively involved in re-organizing their own knowledge structures.

In contrast the more novice performance of many (but not all) students in the experimental pretest, and in the control group showed that the use of lists of pathologies from which items were excluded was sometimes quite effective in reaching a diagnosis. For a number of students this technique proved confusing and inefficient. There seemed to be an overload on what they could remember, and they often lost track with respect to where they were in terms of pathologies excluded. Of course, the method of presenting the simulated cases may have been responsible for some of this confusion, and in real life situations this problem may not have arisen so much. This indicates the need for further refining the diagnostic analysis instruments.

Most exciting of all was the enthusiasm of our expert paediatric cardiologist. It is difficult to record the nature of this enthusiasm, but he assured us it had given him new insights into the teaching of his area of expertise.

The Medical Model of Knowledge Organization

The use of this model in the production of rational conceptual networks was invaluable. The authors have found that this conceptual organization can be applied to a range of medical topics (eg nephrology, arrhythmias, murmurs). The model can be used to discuss individual medical cases or a general medical topic

and it allows for the re-organization of classical text book knowledge into clinically relevant organizations. While the model is a hypothetical construct, it is only useful in so far as it serves as a heuristic. The results in this study indicate that research on the use of such a model should be pursued. As a consequence of doing this study, the authors are already developing a new (and hopefully better) version of how the model might be applied to the area of paediatric cardiology. There is no ultimately correct conceptual network, and attempts to organize medical knowledge in this way best serve those who do the organizing. It is one way of facilitating the active construction of knowledge in order to gain better explanatory and predictive power. It is explicit constructivism.

Analytical Techniques

A novel method of analysis was used on the cases developed by Feltovich (1981). The development of the Conceptual Profiles was straightforward descriptive analysis. The use of the conceptual templates rendered the information thus obtained easier to analyze in terms of the criteria. The criteria used in this study were mainly derived from the literature on the differences between experts and novices. The criterion concerning the use lists from which items are eliminated (versus the construction of schemes) is one which we observed as relevant to this study. The study is primarily descriptive and qualitative in nature. However, the methods of analysis used provided numerical data (frequencies) which permitted non-parametric analyses. The statistical results served to support the descriptive analyses.

IMPLICATIONS

This study indicates that there is a need to deal explicitly with the topic of appropriate knowledge organization in medical training. These preliminary results suggest the need for further research in this, and other related areas. The question of how this categorical change in knowledge organization is made explicit is an open one at this stage. We have attempted to address the problem through the medium of instruction. It could be addressed by text book writers, either explicitly or implicitly. Certain clinical text books are already organizing their text in ways similar to those we are suggesting (Harvey et al, 1984; Petersdorff etal,1983). Clinical workbooks might be a possible way of bridging the differences between the pre-clinical and clinical knowledge organisations.

A further implication is for computer aided instruction. The scope of both testing and implementing the ideas presented in this study are unlimited. This field of inquiry is still in its infancy. The future will show many critical studies which will serve to take the idiosyncratic aspects out of both teaching and learning complex subject matter such as medicine.

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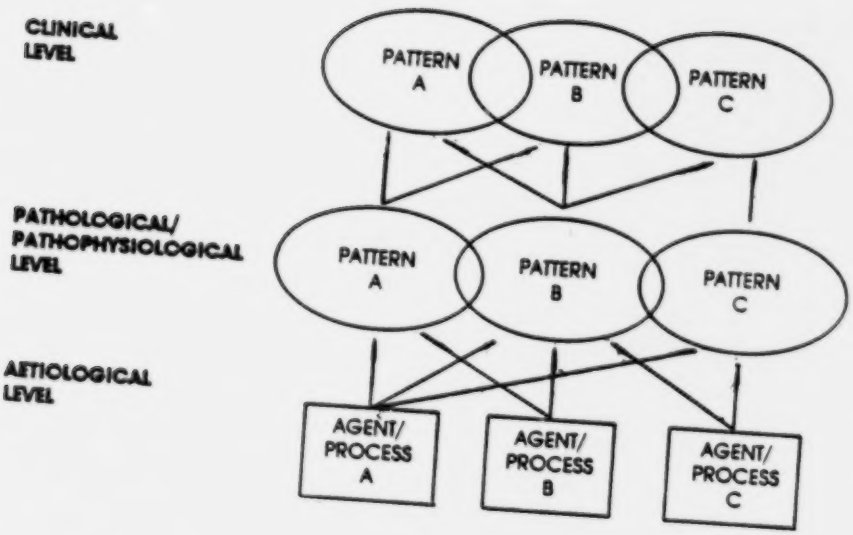

Figure 1: The three levels or categories of concepts and their possible interrelationships

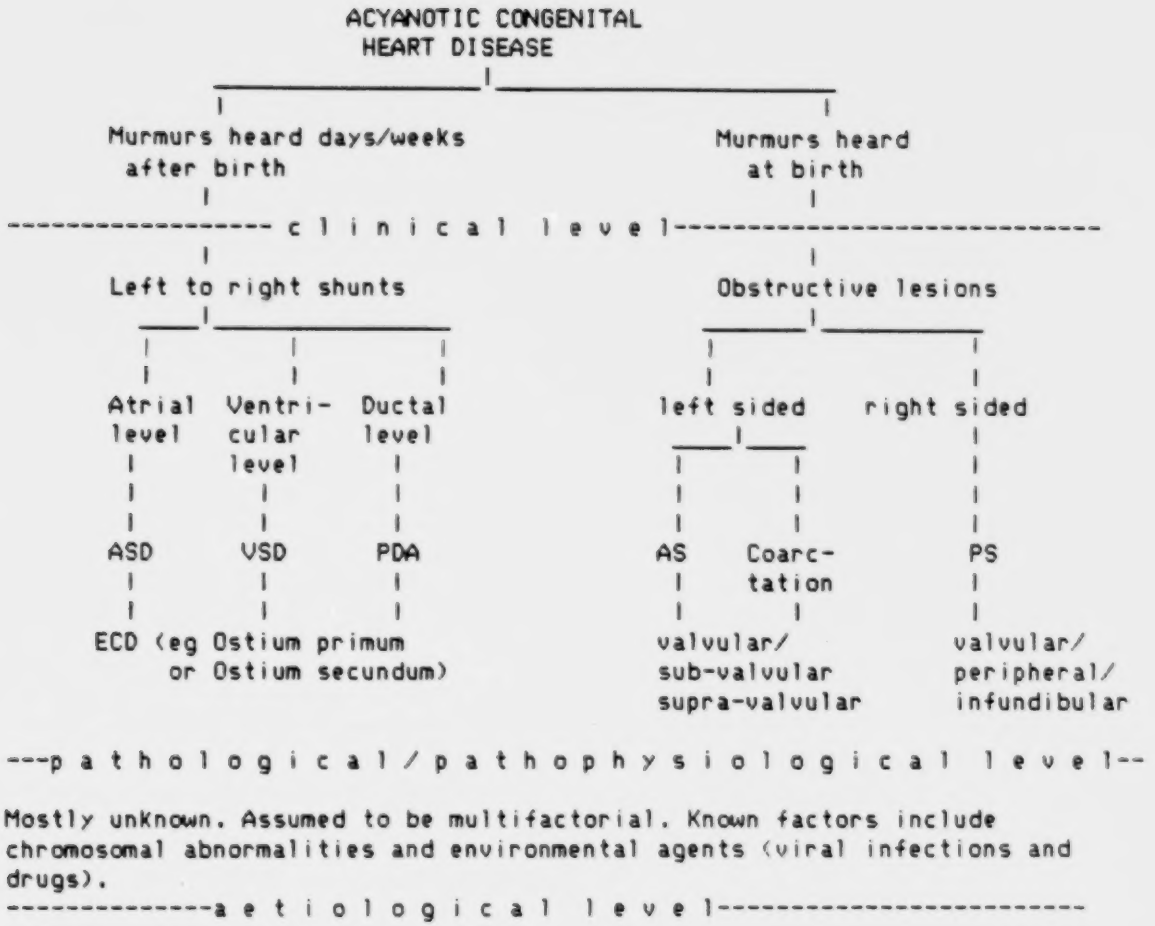
ACYANOTIC CONGENITAL HEART DISEASE
Murmurs heard days/weeks after birth
Murmurs heard at birth
c l i n i c a l l e v e l
Left to right shunts
Obstructive lesions
Atrial level
Ventri-cular level
Ductal level
left sided
right sided
ASD
VSD
PDA
AS
Coarc-tation
PS
ECD (eg Ostium primum or Ostium secundum)
valvular/ sub-valvular supra-valvular
valvular/ peripheral/ infundibular
p a t h o l o g i c a l / p a t h o p h y s i o l o g i c a l l e v e l
Mostly unknown. Assumed to be multifactorial. Known factors include chromosomal abnormalities and environmental agents (viral infections and drugs).
a e t i o l o g i c a l l e v e l

Figure 2. A concept map for acyanotic congenital heart disease, arranged according to the organizing principles for medical concepts.

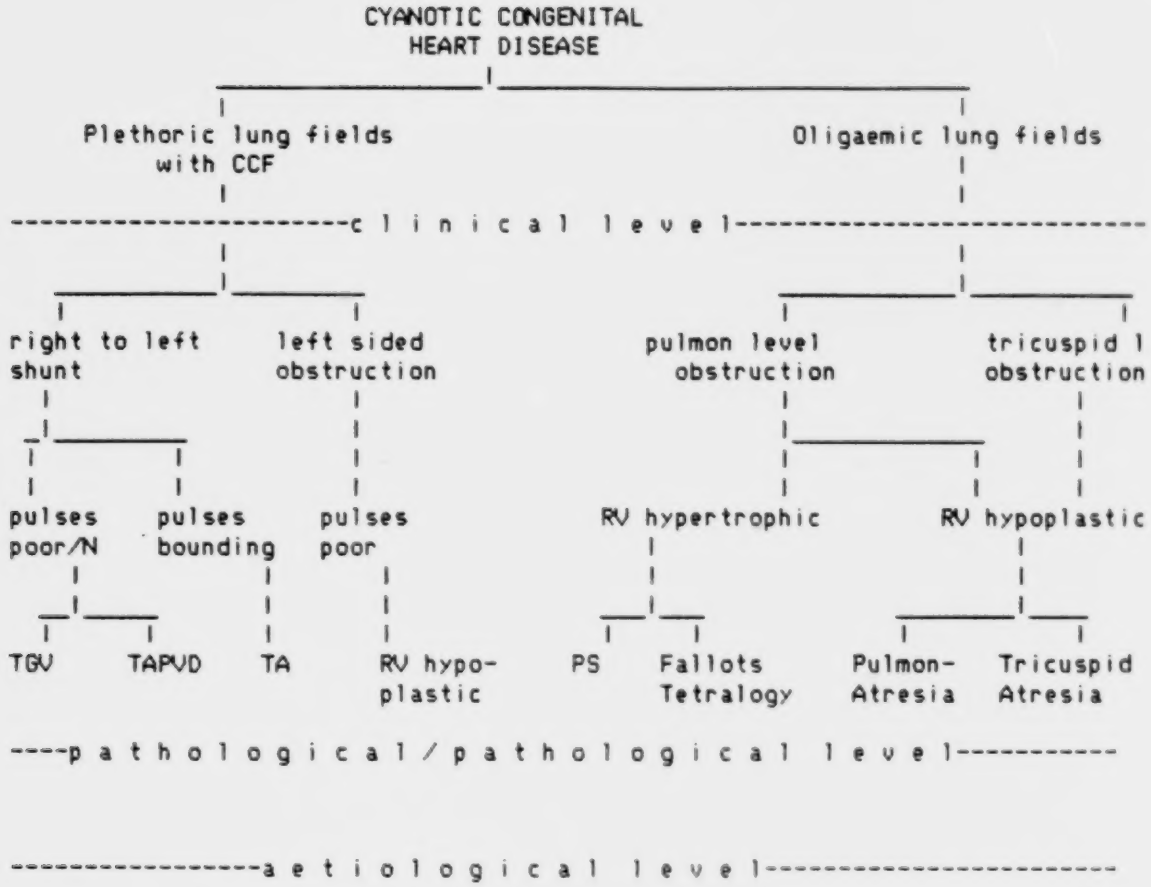

Figure 3. Concept map for Cyanotic Congenital Heart Disease, arranged according to the organizing principles for medical concepts.

TABLE 1.
Comparison of the pretest and posttest frequencies for the Experimental Group.

	Pretest Case 1	Posttest Case 4	Fisher Exact Probability Test
1.Diagnosis			
a.correct	1	2	
b.nearly correct	8	3	p=0.106 NS
c.incorrect	3	7	
2.Organization			
a.schemes/construction	3	6	
b.combination a & c	1	4	p=0.245 NS
c.lists/elimination	6	1	
d.unclassified	(2)	(1)	
3.Connections			
a.connected	4	8	
b.unconnected	7	1	p=0.025 *
c.unclassifiable	(1)	(3)	
4.Relevance			
a.relevant	5	8	
b.nonrelevant	7	4	p=0.206 NS

	Pretest Case 1	Posttest Case 5	
1.Diagnosis			
a.correct	1	4	
b.nearly correct	8	8	p=0.108 NS
c.incorrect	3	0	
2.Organization			
a.schemes/construction	3	9	
b.combination a & c	1	3	p=0.045 *
c.lists/elimination	6	0	
d.unclassified	(2)	(0)	
3.Connections			
a.connected	4	9	
b.unconnected	7	1	p=0.017 *
c.unclassifiable	(1)	(2)	
4.Relevance			
a.relevant	5	11	
b.nonrelevant	7	1	p=0.014 *

TABLE 2.
Comparison of the frequencies for the Experimental and Control Groups.

	Control Case 4	Experiment Case 4	Fisher Exact Probability Test
1.Diagnosis			
a.correct	0	2	
b.nearly correct	3	3	p=0.39 NS
c.incorrect	8	7	
2.Organization			
a.schemes/construction	1	6	
b.combination a & c	1	4	p=0.03 *
c.lists/elimination	9	1	
d.unclassified	(0)	(1)	
3.Connections			
a.connected	4	8	
b.unconnected	7	1	p=0.02 *
c.unclassifiable	(0)	(3)	
4.Relevance			
a.relevant	3	8	
b.nonrelevant	8	4	p=0.07 *

	Control Case 5	Experiment Case 5	
1.Diagnosis			
a.correct	1	4	
b.nearly correct	9	8	p=0.48 NS
c.incorrect	1	0	
2.Organization			
a.schemes/construction	1	9	
b.combination a & c	3	3	p=0.002 **
c.lists/elimination	7	0	
3.Connections			
a.connected	4	9	
b.unconnected	7	1	p=0.017 *
c.unclassifiable	(0)	(2)	
4.Relevance			
a.relevant	4	11	
b.nonrelevant	7	1	p=0.008 **

TABLE 3.
Comparison of the frequencies for the pretest for Experimental Group and posttest for Control Group.

	Pretest Case 1	Posttest Case 5	Fisher Exact Probability Test
1.Diagnosis			
a.correct	1	1	
b.nearly correct	8	9	p=0.33 NS
c.incorrect	3	1	
2.Organization			
a.schemes/construction	3	1	
b.combination a & c	1	3	p=0.26 NS
c.lists/elimination	6	7	
3.Connections			
a.connected	4	4	
b.unconnected	7	7	p=0.67 NS
c.unclassifiable	(1)	0	
4.Relevance			
a.relevant	5	4	
b.nonrelevant	7	7	p=0.56 NS

	Case 1	Case 4	
1.Diagnosis			
a.correct	1	0	
b.nearly correct	8	3	p=0.03 *
c.incorrect	3	8	
2.Organization			
a.schemes/construction	3	1	
b.combination a & c	1	1	p=0.25 NS
c.lists/elimination	6	9	
d.unclassified	(2)	(0)	
3.Connections			
a.connected	4	4	
b.unconnected	7	7	p=0.67 NS
4.Relevance			
a.relevant	5	3	
b.nonrelevant	7	8	p=0.39 NS

TABLE 4.

Analysis of the pre- and posttest data of the experimental group

		Case 1	Case 4	Case 5
E1	1	nearly correct	correct	correct
	2	unclassifiable	scheme/construct	scheme/construct
	3	unclasifiable	connected	connected
	4	relevant	relevant	relevant
E2	1	nearly correct	nearly correct	correct
	2	scheme/construct	unclassifiable	combin list/scheme
	3	connected	connected	unconnected
	4	irrelevant	irrelevant	irrelevant
E3	1	correct	incorrect	nearly correct
	2	scheme/construct	scheme/construct	combin list/scheme
	3	connected	connected	unclassifiable
	4	relevant	relevant	relevant
E4	1	nearly correct	incorrect	correct
	2	list/elimination	list/elimination	scheme/construct
	3	unconnected	unconnected	connected
	4	irrelevant	irrelevant	relevant
E5	1	nearly correct	nearly correct	nearly correct
	2	scheme/construct	scheme/construct	scheme/construct
	3	connected	connected	connected
	4	irrelevant	relevant	relevant
E6	1	incorrect	incorrect	correct
	2	list/elimination	combin list/scheme	scheme/construct
	3	unconnected	unclassifiable	connected
	4	irrelevant	irrelevant	relevant
E7	1	nearly correct	incorrect	nearly correct
	2	list/elimination	combin list/scheme	scheme/construct
	3	unconnected	connected	connected
	4	irrelevant	relevant	relevant
E8	1	incorrect	correct	nearly correct
	2	list/elimination	scheme/construct	scheme/construct
	3	unconnected	connected	connected
	4	irrelevant	relevant	relevant
E9	1	nearly correct	incorrect	nearly correct
	2	list/elimination	combin list/scheme	scheme/construct
	3	unconnected	unclassifiable	connected
	4	irrelevant	relevant	relevant
E10	1	nearly correct	incorrect	nearly correct
	2	list/elimination	scheme/construct	combin list/scheme
	3	unconnected	unclassifiable	unclassifiable
	4	relevant	irrelevant	relevant
E11	1	nearly correct	incorrect	nearly correct
	2	scheme/construct	combin list/scheme	scheme/construct
	3	connected	connected	connected
	4	relevant	relevant	relevant
E12	1	incorrect	nearly correct	nearly correct
	2	unclassifiable	scheme/construct	scheme/construct
	3	unconnected	connected	connected
	4	relevant	relevant	relevant

TABLE 5

Analysis of posttest data of the control group

		Case 4	Case 5
C1	1	incorrect	nearly correct
	2	list/elimination	combin list/elim
	3	connected	connected
	4	relevant	relevant
C2	1	nearly correct	nearly correct
	2	list/elimination	list/elimination
	3	unconnected	unconnected
	4	relevant	relevant
C3	1	incorrect	nearly correct
	2	combin list/scheme	combin list/scheme
	3	connected	connected
	4	irrelevant	irrelevant
C4	1	nearly correct	nearly correct
	2	list/elimination	list/elimination
	3	connected	unconnected
	4	irrelevant	irrelevant
C5	1	incorrect	nearly correct
	2	scheme/construct	scheme/construct
	3	connected	connected
	4	irrelevant	relevant
C6	1	incorrect	nearly correct
	2	list/elimination	list/elimination
	3	unconnected	connected
	4	irrelevant	unclassifiable
C7	1	incorrect	nearly correct
	2	list/elimination	list/elimination
	3	unconnected	unconnected
	4	unclassifiable	irrelevant
C8	1	incorrect	nearly correct
	2	list/elimination	list/elimination
	3	connected	unconnected
	4	irrelevant	irrelevant
C9	1	nearly correct	incorrect
	2	elimination	list/elimination
	3	unconnected	unconnected
	4	irrelevant	irrelevant
C10	1	incorrect	nearly correct
	2	list/elimination	list/elimination
	3	unconnected	unconnected
	4	irrelevant	relevant
C12	1	incorrect	nearly correct
	2	list/elimination	unclassifiable
	3	unconnected	unconnected
	4	irrelevant	relevant

TABLE 6

Analysis of the three cases by the expert paediatric cardiologist

	Case 1	Case 4	Case 5
1	correct	correct	correct
2	scheme/construct	combination a&c	scheme/construct
3	connected	connected	connected
4	relevant	relevant	relevant

APPENDIX A

Verbatim transcript of the interview with Student E6 on the diagnostic task, Case 1, with the profile of student concepts considered in this diagnosis (Possible = ?, Affirmed = +, Negated = -).

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Interviewer: L.Z.
Date: Nov. 1984
Pretest Case 1
Code Number: Eo

DESCRIPTION:

1. Can I comment? From that I'm not quite sure of the values, but I should that this child is a little bit small for his age. Not quite sure.

HISTORY:

2. (No comment)

3. O.K.

4. O.K. Fine. Already I'm starting to think about things like a P.D.A. PDA ?

5. At this stage I'd just like to know a bit more about the murmur itself.

6. O.K.

7. O.K.

8. (No comment)

9. L.Z. Any hunches so far?
Well, basically what I'm thinking about is an acyanotic congenital heart disease. I wouldn't like to go any further at this stage. ACYANOTIC CHD ?

PHYSICAL EXAMINATION:

10. O.K.

11. Fine.

12. (No comment)

13. .....this blood pressure that's higher in the legs. I'd like to know whether this is a supine blood pressure or an erect blood pressure. I would be thinking in terms of coarctation of the aorta, if this was a supine. COARCTATION ?

14. Well that sort of rules out a coarctation of the aorta. COARCTATION -

15. Obviously we have throughout the history and examination - there's minimal signs of pulmonary congestion. We're thinking in terms of an A.S.D. or a V.S.D. at this stage. PULMONARY CONGESTION -

ASD ? VSD ?

16. Fine. It s normal.

17. .....Um...so we've got a systolic thrill which..we ruled out in A.S.D. Now I must think in terms of a V.S.D. or a P.D.A., but I'll wait till I hear exactly what the murmur is before I comment on that.

ASD -
VSD ?
PDA ?

18. O.K. Well, if the first heart sound is normal it means that rules out any mitral or tricuspid valve lesions.

MITRAL OR TRICUSPID VALVE LESIONS -

19. This..murmur is...would indicate possibly an aortic stenotic lesion. Or it could be a V.S.D.

AS LESION -
VSD ?

20. Um.....This could be indicative of an aortic incompetence lesion, though as far as a congenital heart disease - I wouldn't really think about that. It could possibly be a...it wouldn't be a V.S.D. - what I'm starting to think about now is that there's more than one lesion in this heart.

AI LESION ?
VSD -
AI LESION +
R HEART FAILURE -

21. It just shows there's no signs of right heart failure basically.

(L.J. So can you pull together from this history what you think.)

So far we have a lesion that's been present from birth, which has never really affected the individual throughout his life. It was picked up as an incidental finding. Um..High on my list must be a V.S.D...or possibly a P.D.A. Those are the two big ones that I'm thinking about at the moment.

VSD ?+
PDA ?+

(Examines)

22. This prominence of the ascending aorta..brings me back again to coarctation, although the negative of coarctation is that the pulses - there's no radiofemoral delay in the pulses - I would definitely think about that at this stage from the X-ray..

COARCTATION ?+

(E.C.G)

23. That would further lead me to think that there's a lesion - the aorta, causing..left ventricular enlargement.

AORTIC LESION +

(L.J. So as final, can you comment on the whole thing?)

Well, at this stage..at the beginning I must admit I wasn't thinking in terms of a coarctation.

COARCTATION?

(L.J. For what reason?)

Well, for one thing, the pulses, although the B.P.s, as I said, - they were supine B.P.s, then I would definitely think of..

(L.J. Oh?)

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it would definitely not be associated with a coarctation, so I wouldn't think of that. But..the murmurs.. this is an ejection systolic murmur, which would fit in with coarctation....um..specially as the murmur in the neck..er..The P.D.A. which I was thinking about in the beginning was ruled from the..character of the murmur. There's no machinery murmur described. A V.S.D. is still a possibility.

COARCTATION ?-

PDA -

VSD ?

Ventricular septal defect. Um....although this prominence of the ascending aorta worries me. I'm sure that's very strongly indicative of a coarctation.. or an aortic stenosis. Now the E.C.G. - that again could be a coarctation or it could be a V.S.D., basically because there's ventricular hypertrophy. Um, I suppose if I had to stick my neck out..I would go for...coarctation of the aorta.

COARCTATION ?

AS ?+

COARCTATION

VSD ?

COARCTATION +

? = possibility

- = ruled out

+ = confirmed

?+ = possibly confirmed

?- = possibly ruled out

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APPENDIX B

Three case histories involving Congenital Heart Disease used to expose the organization of knowledge in expert physicians and medical students (novices). These cases were designed by Feltovich (1981), and are taken from that report.

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Patient Files for the
Cases of the Study

CASE 1

Discrete Membranous Subaortic Stenosis

DESCRIPTION

(1) The patient is an 11 year old boy. He weighs 62 pounds and is 53 inches tall. His presenting problem is that a physician doing a school physical, three months ago, heard a murmur.

HISTORY

(2) The child was born following a normal pregnancy and delivery. He was delivered at full term with a birthweight of 5 pounds, 6 ounces.

(3) A murmur was heard at birth by the attending physician, but there has never been a follow-up of this murmur until the present.

(4) Other than the murmur at birth, there were no problems in the neonatal period. Specifically, the child was not cyanotic in the neonatal period.

(5) The boy led a normal, asymptomatic childhood until the age of 10 years when, during an examination for a school physical, a murmur was noted by the physician doing the exam and he referred the child to the University of Minnesota for evaluation.

(6) His growth and development have been normal when compared to his siblings and he has done well in school.

(7) There is no history of cyanosis or chest pains. He currently participates in baseball, football, and other sports and has no evidence of fatigue or dyspnea on exertion.

(8) There have been no unusual childhood illnesses, and he has had no hospitalization or operations.

(9) The family history is negative for congenital heart disease.

PHYSICAL EXAM

(10) On physical examination, this is a healthy appearing, 11 year old boy. The facies are normal.

(11) There is no cyanosis and the fingers and toes appear normal.

(12) There is no evident respiratory distress. Respiration rate is 16/minute.

(13) The blood pressure in the left arm is 90/70, in the right arm 102/60 and in the leg is 120/60 by auscultation.

(14) The pulses are normal and equal in arms and legs. The pulse rate is 84/minute.

(15) The chest is symmetrical with no bulge. There is mild asymmetry of the back associated with slight

thoracic scoliosis. The lungs are clear to auscultation.

(16) The apex impulse is in the fifth intercostal space in the midclavicular line.

(17) There is a systolic thrill felt below the right clavicle, along the mid-left sternal border, and in the suprasternal notch.

(18) The first heart sound is normal and there is no systolic ejection click.

(19) A grade 4 over 6 systolic ejection murmur is heard best at the right upper sternal border, but also heard along the left sternal border, and less well throughout the precordium. The murmur is also heard in the neck.

(20) The second heart sound is normal and followed by a grade 1-2 over 6 early diastolic murmur heard best at the second left intercostal space.

(21) Neither the liver nor spleen was palpable.

X-RAY

(22) The chest x-ray shows normal cardiac size and contour and normal vascularity, but prominence of the ascending aorta.

EKG

(23) The EKG shows a QRS axis of between +30° and +45°. The P waves, T waves, and PR interval are normal. The pattern shows probably left ventricular hypertrophy.

CASE 4

Pulmonary Atresia

DESCRIPTION

(1) The patient is a 4 day old male. His weight is 7 pounds 4 ounces and his length is 20 inches. His presenting problem is cyanosis.

HISTORY

(2) The child was born at term following a normal pregnancy and delivery. The mother had no unusual health problems during pregnancy.

(3) The child was cyanotic at birth and because of cyanosis which persisted in oxygen and also mild respiratory distress, he was transferred to St. Paul Children's Hospital.

(4) On the third day of life, a murmur was initially heard and because of this he was transferred to the University of Minnesota Hospitals.

(5) Feeding was started on the first day of life and went well although the child regurgitated on several occasions.

(6) The family history is negative for congenital heart disease.

PHYSICAL EXAM

(7) On physical examination, the child is vigorous

and has a good cry. The facies are normal.

(8) He is markedly cyanotic even in an atmosphere of 100% oxygen. The cyanosis is generalized.

(9) Respiratory rate varies from 50 to 100/minute.

(10) The blood pressures in the arm and leg are 40 millimeters mercury by simultaneous flush methods.

(11) The peripheral pulses are normal and equal in arms and legs. The pulse rate is 130/minute.

(12) The chest is symmetrical. On auscultation, the lungs show no rales or rhonchi.

(13) There are no heaves or thrills. The apex impulse is in the 4th intercostal space in the mid-clavicular line.

(14) The first heart sound is loud and there is a grade 2 over 6 systolic murmur along the lower left sternal border. There is little radiation. This murmur is not heard in the back or head.

(15) The second heart sound is single and perhaps slightly increased in intensity. There is no gallop or diastolic murmur.

(16) The liver edge is palpable 2 cm. below the right costal margin. The spleen is not palpable.

<u>X-RAY</u>

(17) The X-ray shows the heart to be somewhat enlarged with the right atrium also noted to be enlarged.

The pulmonary vasculature is diminished. There is no evidence of pulmonary infiltrate. The base of the heart is narrow.

EKG

(18) The EKG has a QRS axis of $+50^{\circ}$ and shows sinus tachycardia, right atrial enlargement, and non-specific ST and T wave changes. In addition, the EKG shows a small R wave in the right precordium suggesting or compatible with a hypoplastic right ventricle.

CASE 5

Coarctation of the Aorta and

Bicuspid Aortic Valve and Mitral Insufficiency

DESCRIPTION

(1) The patient is a 9 month old boy. He weighs 18 pounds, 2½ ounces and is 28½ inches long. The presenting problem is a heart murmur noted by a private physician three weeks ago on a routine examination.

HISTORY

(2) The child was born following a normal pregnancy and delivery. He was delivered, along with a twin, at full term with a birth weight of 6 pounds 14 ounces. The twin is asymptomatic. There is a healthy 4 year old brother.

(3) There were no problems at birth or in the neonatal period. Specifically, there were no murmurs heard or cyanosis in the neonatal period.

(4) Although the child had been checked periodically, no murmur was noted until three weeks ago. Cyanosis has never been noted.

(5) There have been no problems with feedings, that is, no unusual perspiring, tiring, or slowness. His suck is good.

(6) There have been no unusual illnesses, in particular, no recurrent respiratory infections.

(7) His growth and general development have been normal when compared to his 4 year old brother. He is active but mother thinks somewhat less active than his twin or 4 year old brother.

(8) The family history is negative for congenital heart disease.

PHYSICAL EXAM

(9) On physical examination, this is a well-developed, well nourished alert 9 month old child. Facies are normal.

(10) There is no cyanosis and fingers and toes are normal.

(11) There is no evident respiratory distress. Respiratory rate is 16/minute.

(12) Blood pressures were 140 in the left arm and 80 in the left leg by simultaneous flush method. Blood pressure in the right arm by auscultation 140/90. Blood pressure in left arm by auscultation 160/90.

(13) The radial pulses are bilaterally sharp and readily palpable. Femoral pulses are not palpable bilaterally. Pulse rate is 110/minute.

(14) The neck is supple with no masses. There is no thrill in the suprasternal notch.

(15) The chest is symmetrical. The lungs are clear to auscultation.

(16) The apex impulse is in the fifth intercostal space in the mid clavicular line.

(17) There are no heaves or thrills.

(18) The first heart sound is split with the second component perhaps representing an apical systolic ejection click. The second heart sound is split and P_2 is slightly accentuated.

(19) There is a grade 3 over 6 soft systolic murmur at the apex which radiates to the axilla.

(20) There is a grade 1 to 2 over 6 short, harsh systolic murmur heard best in the aortic area. This murmur is not well heard in the interscapular area.

(21) The liver is palpable 2 cm below the right costal margin and the spleen is not palpable.

X-RAY

(22) The X-ray shows moderately enlarged heart and left atrial enlargement. The pulmonary vasculature is prominent and perhaps slightly increased.

EKG

(23) The EKG shows biventricular hypertrophy and left atrial enlargement. The axis is normal.

END

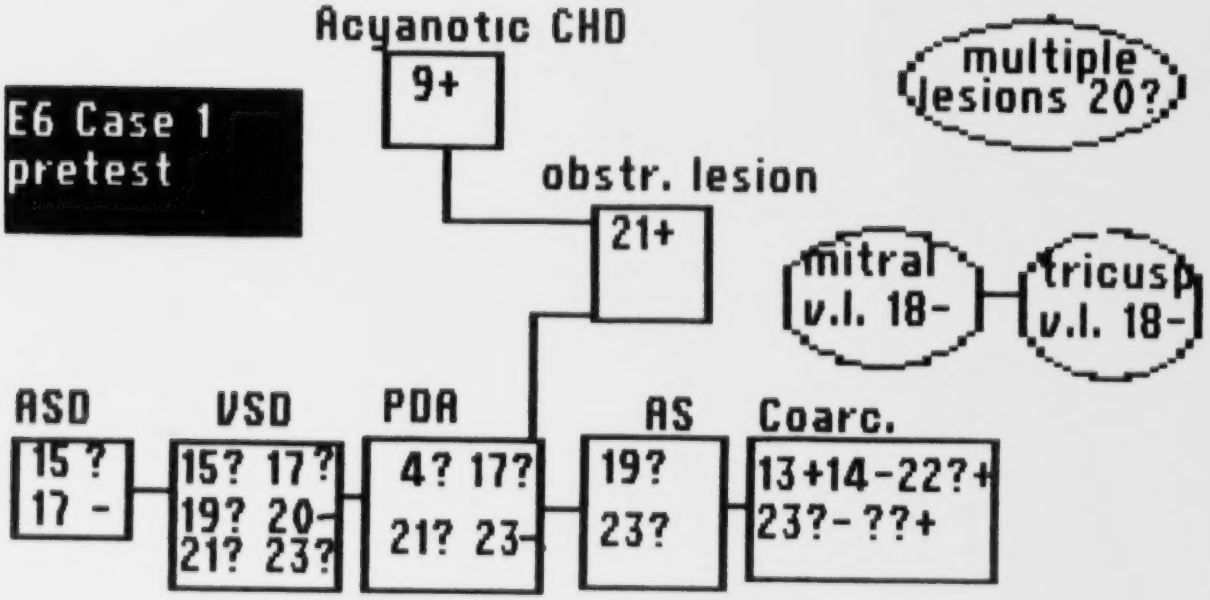
APPENDIX C

Representation of explicit knowledge used by student E6 during the diagnosis of Case 1.

The profiles from individual transcripts were represented on the conceptual template designed by the authors to incorporate all the important, and relevant concepts in the topics of Acyanotic Congenital Heart Disease and Cyanotic Congenital Heart Disease (See Figures 2 & 3). Every concept mentioned by the respondent was represented on the template, and the status of each concept was indicated (possible = ?, affirmed = +, negated = -). Concepts considered by the respondent which are additional to those on the template indicated. Links between the concepts were only indicated when they were referred to either implicitly or explicitly by the respondents.

These knowledge representations were constructed for every interview done in this study. The one represented here is selected to show how the information from the profile (Appendix A) was represented for purposes of comparison and checking between authors' analyses.

The analyses using the four criteria (correct diagnosis, type of knowledge organization, connected concepts relevant concepts) were done on these templates. The data from these analyses are found in Tables 4 and 5.


E6 Case 1
pretest
Acyanotic CHD
9+
multiple
lesions 20?
obstr. lesion
21+
mitral
v.l. 18-
tricusp
v.l. 18-
ASD
15 ?
17 -
VSD
15? 17?
19? 20-
21? 23?
PDA
4? 17?
21? 23-
AS
19?
23?
Coarc.
13+14-22?+
23?- ??+